A comparison between bagasse and water efficient alternatives using KOH/AQ pulping

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ABSTRACT

Numerous crops grow in sugar regions that have the potential to increase the amount of biomass available to a small bagasse-based pulp factory. Arundo donax and Sorghum offer unique advantages to farmers compared to other agricultural crops. Sorghum bicolour requires only 1/3 of the water of sugarcane. Arundo donax is a very high yield crop, it can also grow with little water but it has the further advantage in that it is also highly stress tolerant, making it suitable for land which is unsuited to other crops. Pulps produced from these crops were benchmarked against sugarcane bagasse pulp.

Arundo, sorghum and bagasse were pulped using KOH and anthraquinone to 20 Kappa number so as to produce a bleachable pulp which is suitable for making photocopier paper and tissue products. The unbleached sorghum pulp has better tensile strength properties than the unbleached Arundo pulp (43.8 Nm/g compared to 21.4 Nm/g) and the bleached sorghum pulp tensile strength was similar to bagasse (28.4 Nm/g). At 20 Kappa number, sorghum pulp had acceptable yield for a non-wood fibre (45% c.f. 55% for bagasse), Arundo donax pulp had low tensile strength, and relatively low yield (38.7%), even for an agricultural fibre and required severe cooking conditions to achieve similar delignification to sugarcane bagasse or sorghum. Sorghum and Arundo donax produced thicker handsheets than bagasse (>160 µm c.f. 122 µm for bagasse). In preliminary experiments sorghum and bagasse responded slightly better to Totally Chlorine Free peroxide bleaching (QPP), although none achieved a satisfactory brightness level and further improvement would be required to produce a bleached pulp.

INTRODUCTION

Australia and many other countries have increasingly limited high quality water resources for agriculture. Maximising the productivity of marginal agricultural land using high water efficiency agricultural crops has sustainability advantages and economic opportunities while caustic potash pulping can produce fertiliser as a by-product from the black liquor. . Arundo donax and sorghum could be grown on marginal land near to sugarcane plantations thus increasing the available biomass.

Arundo donax (Figure 1) is a very high biomass yielding, drought and saline tolerant plant. It has been the subject of numerous pulping studies [1-8], particularly by Shatalov and co-workers. It grows to 45-60 t/ha/y [9] when grown on arable land using recycled sewerage. Under ideal conditions, it can grow up to 5 m tall in a season. These properties have also led to it being declared a noxious weed in some jurisdictions such as in California.

A recent Australian study investigated its suitability for pulp, paper and biofuel production [9]. The pulp assessment in this earlier study was performed using bisulfite and kraft processes. Bisulfite pulping produced a pulp with low bleached pulp brightness (~60% ISO) with a notable high dirt count. Kraft pulping followed by ECF bleaching (DEpD) was more successful, achieving 86.5%ISO brightness. However, pulp yield remained very low (~38%) [9].

Figure 1 Arundo donax; growth in 1 season under favourable conditions [9]

Sorghum can be classified as sweet sorghum, grain sorghum and forage sorghum [10]. Sorghum is the fifth most widely grown cereal crop [11]. Grain sorghum has a larger grain head and higher starch content whereas sweet sorghum has higher sugar content in its stalk.

Table 1 Composition of sweet sorghum and forage sorghum [11].

Component	Sweet sorghum	Forage sorghum
Structural carbohydrate	53.4	58.6
Cellulose	26.3	29.5
Hemicellulose	20.0	20.5
Lignin	7.1	8.6
Non-structural carbohydrate (i.e. glucose, sucrose, fructose and starch)	36.4	27.7

Sweet and forage sorghum is of interest because it has high carbohydrate content and can be intercropped with sugarcane and processed at a sugar factory for ethanol production. Sweet and forage sorghum have a high tolerance to salt and drought [10-15] whilst producing high amounts of biomass [11, 16-19]. It requires far less water and little fertilizer [13, 20]. It has a high amount of fermentable sugar [16, 19] and its juice has even been claimed to be more suitable for fermentation to ethanol than sugarcane [10].

Sweet and forage sorghum is highly adaptable to different climates [12]. Although they are believed to originally come from tropical regions [13, 21], it grows well in temperate climates [12, 13, 17, 22]. Almodares and Hadi [23] advocate for their use in hot and dry countries. For the present study, forage sorghum will be evaluated as a feedstock for making pulp.

In a similar way to which Arundo donax is a potential supplementary feedstock, there is good compatibility with growing sorghum in sugar regions, increasing the biomass available for pulping.

In this study, results from pulping experiments with Arundo donax and sorghum are compared to sugarcane bagasse as it is used commercially in Australia, using comparable pulping and bleaching conditions.

EXPERIMENTAL PROCEDURE

Samples of Arundo donax were obtained from the Queensland Government Department of Employment, Economic Development and Innovation (DEEDI). Forage Sorghum (variety 'Sugar Sweet') was obtained from EnviroFibre in the Babinda region in North Queensland.

Both plants were stripped of extraneous leaf material and cut into 30-40 mm lengths in order to fit into the reactor. In the case of the sorghum, the grain head was also removed. The prepared plant material is shown in Figure 2.

Figure 2 The prepared sorghum (top left), Arundo donax (top right) and bagasse (bottom)

The experimental program was carried out at the Australian Pulp and Paper Institute (APPI) at Monash University. Pulping experiments were conducted using a tumbling air-bath reactor (8x2 litre cells). The samples were cooked with varying concentrations of potassium hydroxide (13-61% KOH) and 0.1% anthraquinone at 170 °C and 6:1 liquor to fibre ratio. These conditions had previously been successful for bagasse in unpublished work. To reach kappa 20, cooking time for the Sorghum and the bagasse was 75 min, but 150 min was required for the Arundo donax.

The unbleached pulp was screened using a 200 µm Packer screen in order to remove uncooked material and contaminants.

Bleaching of the pulp samples was undertaken using a peroxide process - QPP - according to the method used by Byrd [2] whereby 85 ISO brightness Arundo donax pulp was produced. The process thus included a chelating stage (Q) to remove transition metals which consume peroxide, followed by two consecutive peroxide stages (PP). The conditions employed are shown in Table 2. In these preliminary experiments, only diethylene triamine pentaacetic acid (DTPA) was used as Diethylenetriaminepentakis(methyl)phosphonic acid (DTMPA) was unavailable. The bleaching experiments were preliminary in nature and no effort was made to optimise bleaching conditions.

Brightness was measured using standard ISO Standard 2470-2 illuminant D65.

Table 2 Bleaching conditions

Chelating stage (Q stage)	2 stages of peroxide bleaching (each P stage)

pH 5 (adjusted with sulphuric acid)	4% H_2O_2 on OD fibre
DTPA 0.5% on OD fibre	4% NaOH on OD fibre
4% consistency	0.2% DTPA on OD fibre
55 °C	0.5% $MgSO_4$ on OD fibre
30 min	0.5% $NaSiO_3$ on OD fibre
	12% Consistency
	105 °C
	90 min

Handsheet testing was performed at APPI. Caliper was measured using T-411, and tensile strength was measured using T-494 om-96 (modified to 10 mm/min). 60 gsm handsheets were made.

RESULTS AND DISCUSSION

Kappa Number

Kappa number results versus % KOH are presented in Figure 3. For sorghum and bagasse, it was found that 29% KOH on dry fibre (allowing for differences in molecular weight between KOH and NaOH, 29% KOH is equivalent to 16% as Na_2O on dry fibre) is required to produce a pulp that is suitable for bleaching; a relatively low amount compared with wood. The low chemical usage is due to the low lignin content and porous structure of these crops. The Arundo donax needed to be cooked for much longer (150 min) and 45% KOH on dry fibre (equivalent to 25% as Na_2O) was needed to produce a bleachable pulp. The Arundo donax required far more aggressive conditions for pulping due to its higher lignin content and it had a very rigid impermeable stem. The pulping conditions required for Arundo donax were more similar to that used for pulping wood rather than for most agricultural fibres. This level of chemical addition would likely be uneconomical at the industrial scale.. Only 1 datum was obtained for bagasse.

Pulp Yield

The pulp yield for agricultural fibres (using chemical pulping) is usually lower than for wood fibres (50-60%). The pulp yield in this small scale study is shown as a function of Kappa number in Figure 4.

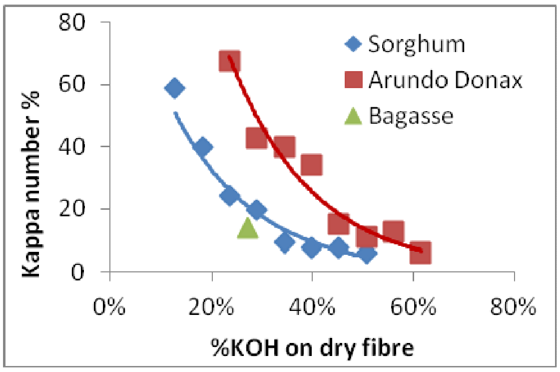

Figure 3 Effect of KOH concentration on Kappa number (6:1 liquor to fibre ratio; 170 °C; 75 min for bagasse and sorghum, 150 min for Arundo donax)

A commercial bagasse pulp typically has a pulp yield of around 45-55%. At 20 Kappa number, the pulp yield for Arundo donax was low, 38.7%, which is consistent with literature values (37% was reported by Williams [9]) and the pulp yield for forage sorghum was 45.0 (literature values for sweet sorghum are 42.8% [24], to 45.8% [25]). Pulp yield for bagasse pulp was 55.0%. The results are shown in Figure 4.

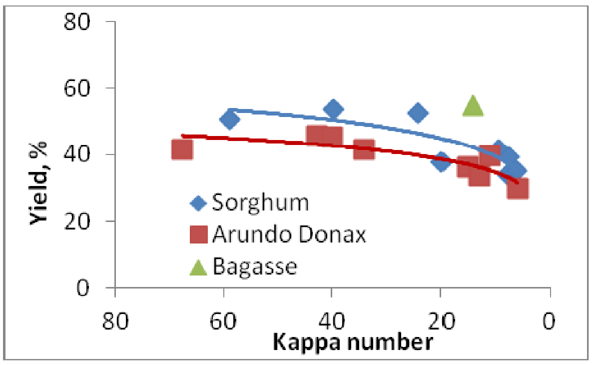

Figure 4 Effect of kappa number on yield (6:1 liquor to fibre ratio; 170 °C; 75 min for bagasse and sorghum, 150 min for Arundo donax)

Brightness

The results of the brightness experiments are shown in Table 3. For comparison purposes a commercial Thai bagasse pulp was measured at 77 brightness. In the preliminary unoptimised experiments, this brightness level could not be reached, however in recent unpublished work by the author this brightness level has been reached using KOH bagasse pulp and so process optimization should aim to reach that level eventually.

The preliminary investigation suggests that sorghum and bagasse pulp may have a better bleaching response than the Arundo donax pulp, even though it had a higher initial brightness.

Table 3 Brightness of pulp samples

	Sorghum	Arundo donax	Bagasse pulp
Unbleached	31.0	37.9	28.1
QP	62.4	52.5	54.8
QPP	67.5	62.1	62.8

Drainage properties

A common criticism of non-wood pulp generally is the perceived poor drainage properties. Unbleached Arundo donax pulp had excellent drainage properties (710 CSF), bagasse was 690 CSF and the sorghum was 640 CSF; all were satisfactory. The fines content of a bagasse pulp would be expected to be higher due to the large pith section of the sugarcane plant compared to Arundo donax and sorghum. The treatment used in this study was developed previously [26]. By comparison, commercial bleached kraft bagasse pulp was 370 CSF.

Tensile strength

The tensile strengths of all three pulp samples (unrefined) are presented in Table 4. Unbleached bagasse pulp was not tested.

The bleaching process had a large effect on tensile strength. Following bleaching, the tensile strength of the sorghum handsheets was very close to bagasse pulp although it had lower density and the tensile strength of Arundo donax pulp was very low, 13.3 Nm/g. The very good initial drainage of the Arundo donax might allow significant refining to be performed to improve the tensile strength.

Table 4 The tensile strength properties of bleached and unbleached pulp (unrefined)

	Apparent density (bleached), g/cm^3	Unbleached pulp tensile index, Nm/g	Bleached pulp tensile index, Nm/g
Sorghum	0.363	43.8	28.8
Arundo	0.354	21.4	13.3
Bagasse	0.493		28.4

Caliper

For the 60 gsm handsheets, the bagasse pulp produced the thinnest handsheets of the three types of pulp (122 µm; bleached). The Arundo donax produced the thickest handsheets (169 µm bleached) and the sorghum was intermediate (164 µm for bleached). Bagasse pulp has a larger fibre diameter (20-21 µm [27]) compared to Arundo (15 µm, [8]) but they have similar wall thickness of 5.0 µm [8, 27]. This may have lead to the higher flexibility of bagasse fibre. Values for forage sorghum were not obtained.

CONCLUSIONS

This preliminary study has determined that it is possible to pulp sorghum and Arundo donax to a Kappa number below 20 using potassium hydroxide and anthraquinone. Sorghum had reasonable tensile index (43.8 Nm/g); its pulp yield (45%) is lower than bagasse (55%) and its bleachability is similar. The Arundo donax required a very large amount of chemicals to pulp (~45% KOH on OD fibre) to obtain a bleachable pulp. The tensile strength properties of Arundo donax are also a concern (21.4 Nm/g for unbleached) and finally the perception that it is an intrusive weed might restrict commercialisation in Australia for pulp and paper production.

Of the two crops, it appears that sorghum is more suitable for complementing bagasse as a feedstock for a pulp mill.

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